A User's Introduction to JWST

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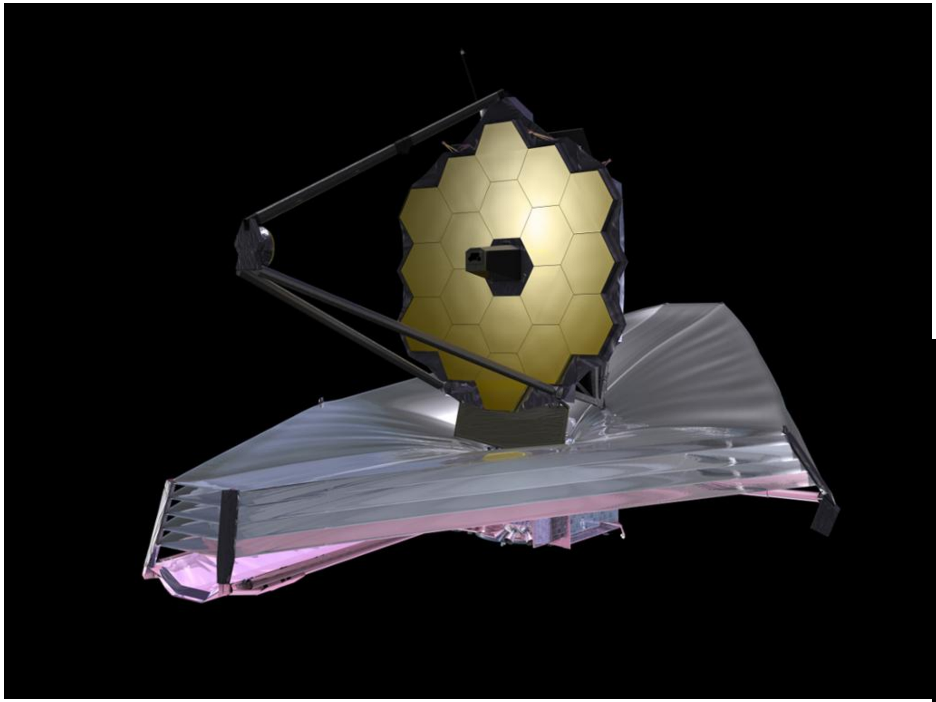
JWST Is …



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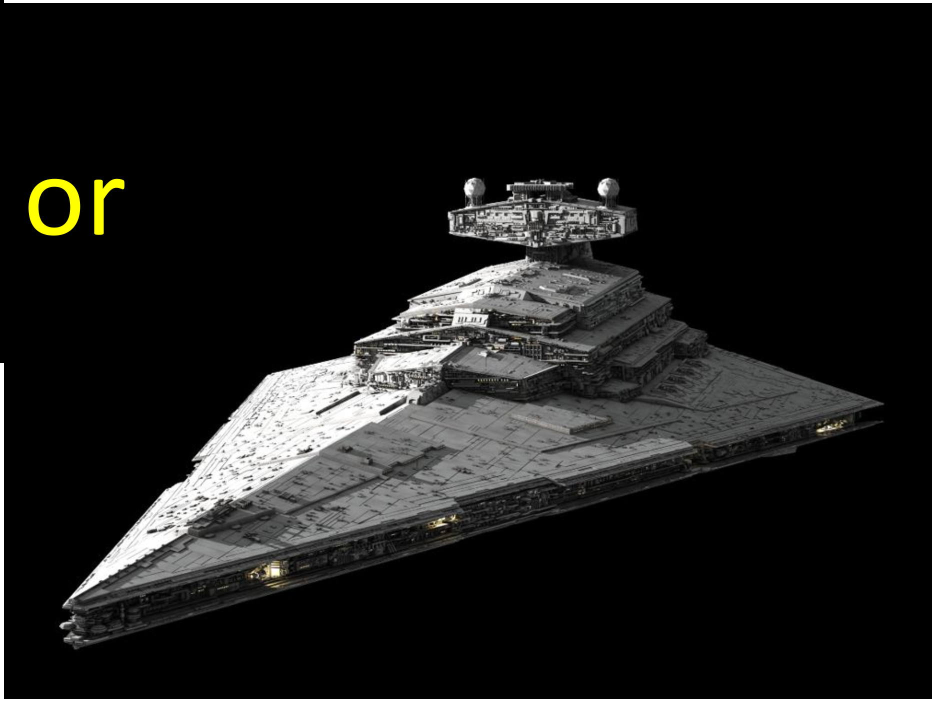
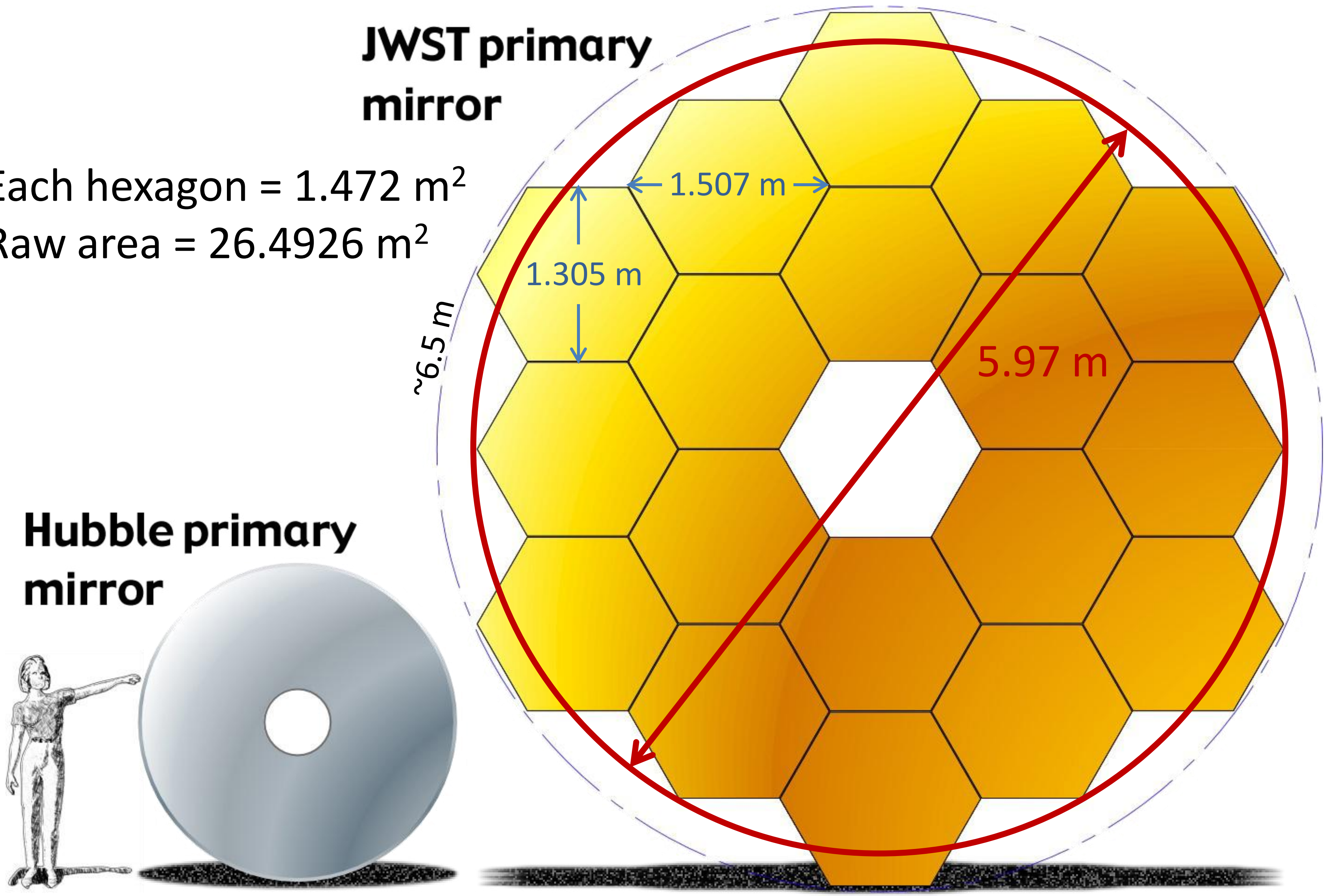


Collecting Area

Each hexagon = 1.472 m^2
Raw area = 26.4926 m^2



Why This Talk Now?

- JPL is a significant contributor to JWST (not just MIRI!), so it is time to inform the JPL community what they are getting
- 5 years to launch – time to start planning!
  - Science simulations, data policy: now
  - Commissioning proposals: late 2016
  - Cycle 1 Call for Proposals: late 2017
  - Launch: late 2018
  - Cooldown and commissioning: Launch + 6 months
  - Cycle 1 commences: mid-2019

What I’m Not Going to Discuss

- History
- Roles & responsibilities
- Designs and challenges
- Status & schedule
- “Why does it cost so %@#^ much?”
- Pretty pictures of hardware
- Maybe another day if there is interest, but …

Much of JWST is built, and barring disaster, it will fly. Therefore, what can we do with it?

Science Themes/Drivers

- The End of the Dark Ages: First Light and Reionization
  - seeks to identify the first bright objects that formed in the early Universe, and follow the ionization history.
- Assembly of Galaxies
  - will determine how galaxies and dark matter, including gas, stars, metals, physical structures (like spiral arms) and active nuclei evolved to the present day.
- The Birth of Stars and Protoplanetary Systems
  - focuses on the birth and early development of stars and the formation of planets.
- Planetary Systems and the Origins of Life
  - studies the physical and chemical properties of solar systems (including our own) and where the building blocks of life may be present.

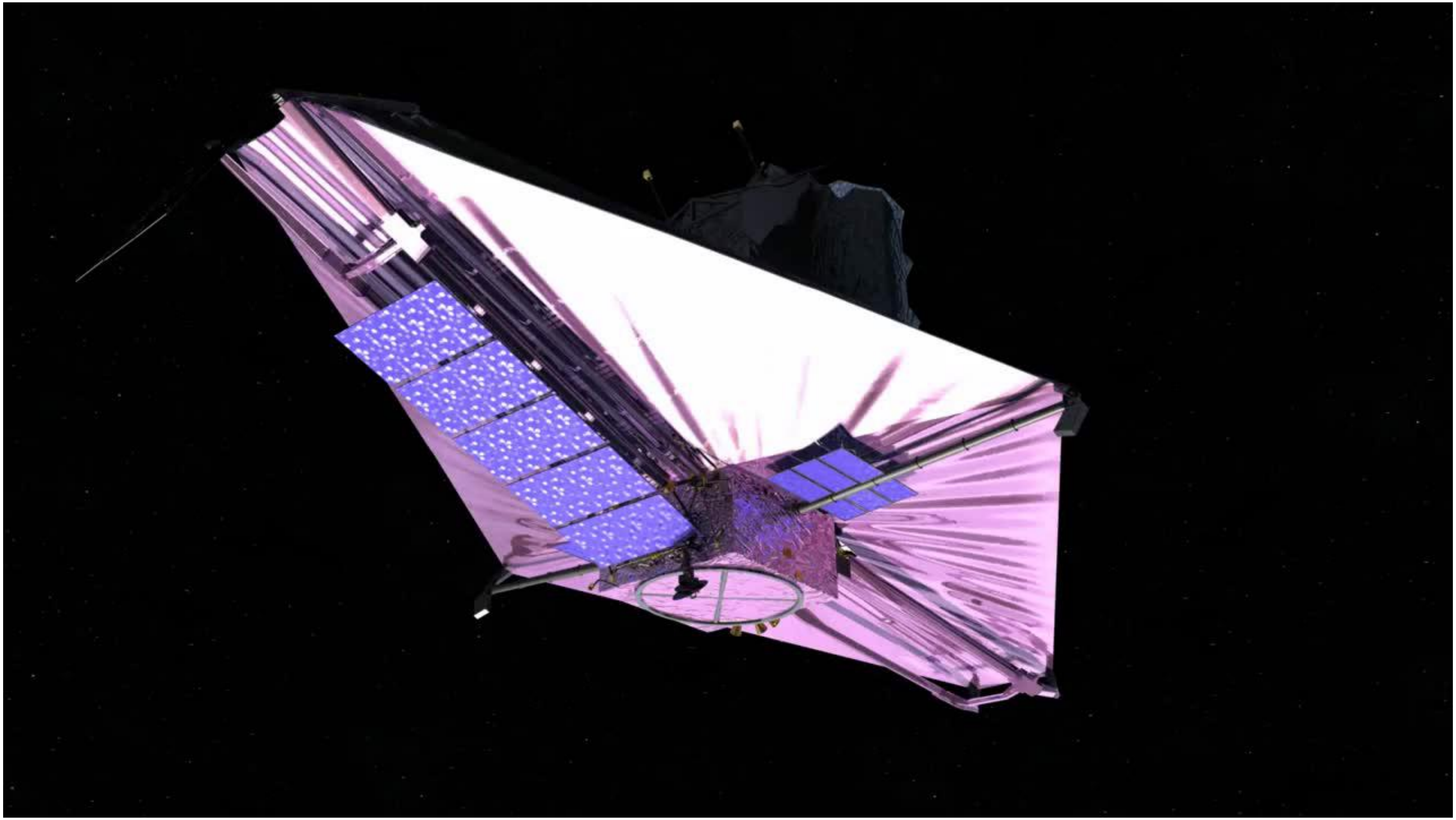
New Interests Since Then

- Exoplanets/Transits
  – Driven by Kepler and Spitzer/IRAC successes
- Solar System planets/moons/objects
  – Can track all planets from Mars and beyond
  – Need to be careful of brightness

- These place new stresses on the observatory (but no requirement changes allowed):
  – Extra stability – both pointing and electronic
  – Moving target acquisition and guiding

Instruments

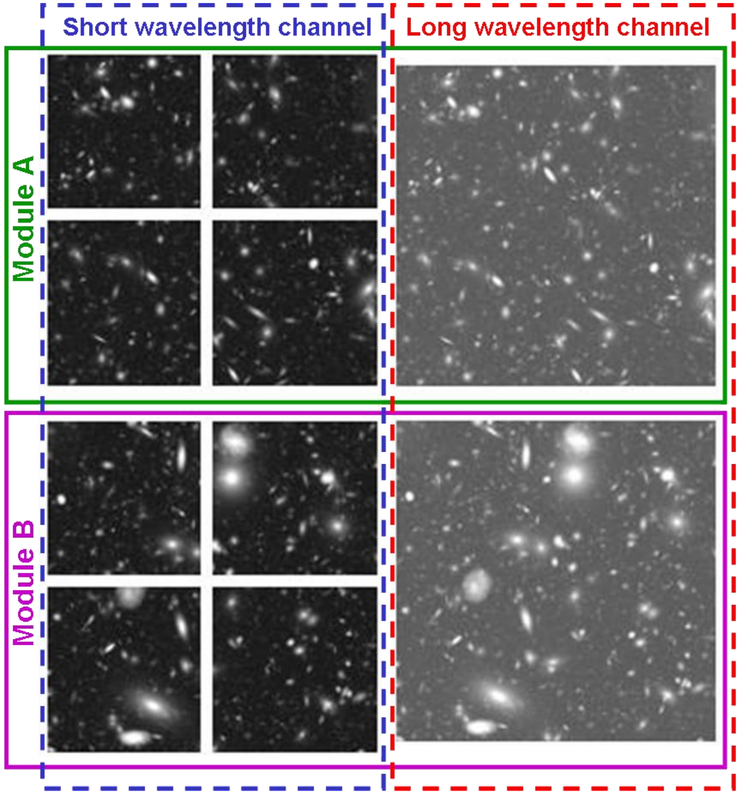
Instrument Complement



See http://www.jwst.nasa.gov/instruments.html for the video

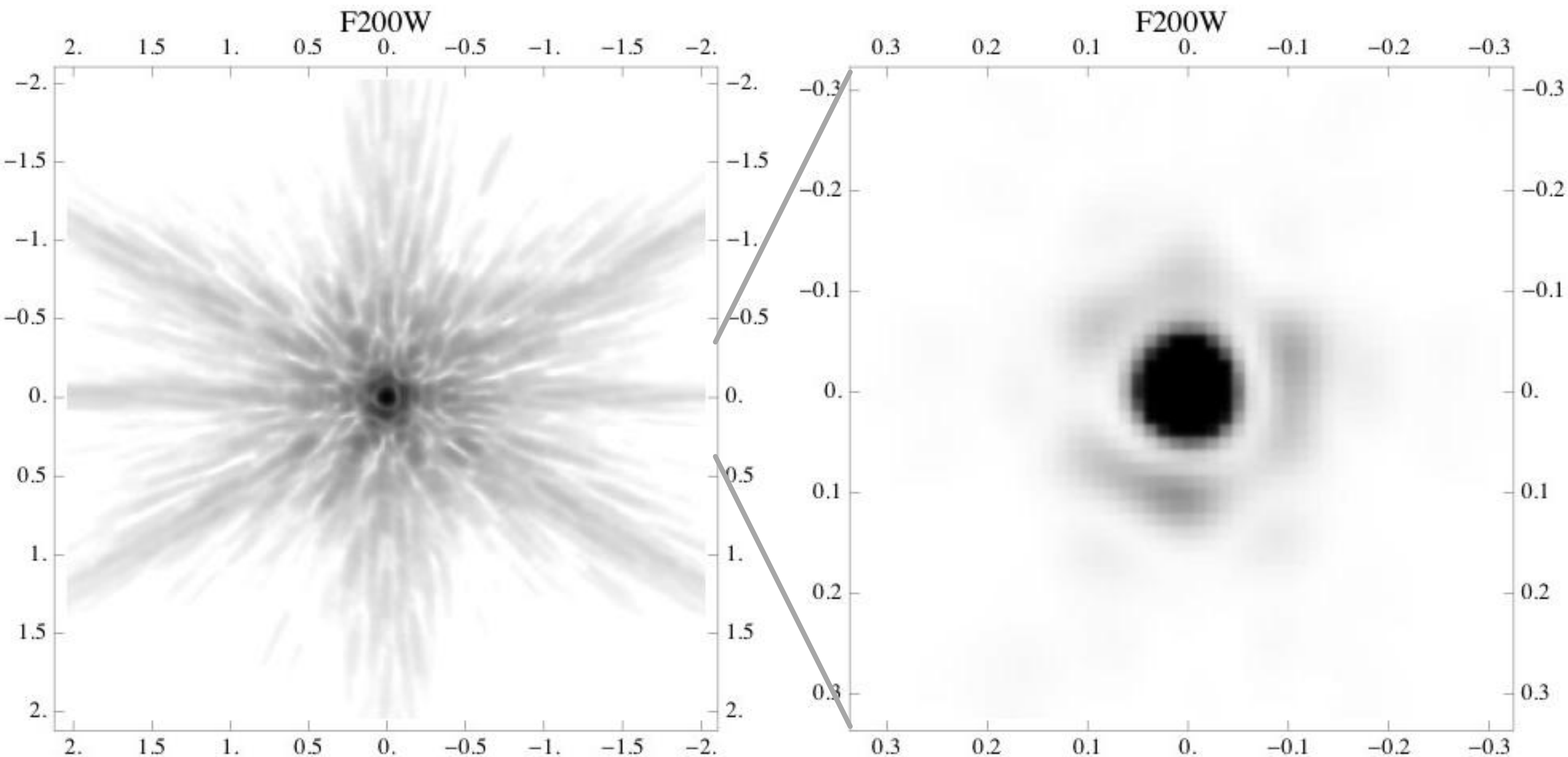
NIRCam

- Imaging from 0.7 to 4.8 μm
- 2.2 x 4.4 arcmin FOV
  - 0.032 "/pix < 2.4 μm
  - 0.065 "/pix > 2.4 μm
  - Short and long observable simultaneously



- Coronagraphic capability
- R=2000 grism for 2.4 - 5 μm slitless spectroscopy
- Serves as wavefront sensor

Predicted Point Spread Function



Log stretch

Linear stretch

NIRCam Filters & Sensitivity

Wavelengths in µm, Sensitivity in nJy, 10σ in 10000 s

Short Wavelength Module

Name	Center	Bandpass	Sensitivity	Use
F150W2*	1.5	1		DHS Blocking
F070W	0.7	0.175	20.9	General purpose
F090W	0.9	0.225	14.3	General purpose
F115W	1.15	0.2875	11.8	General purpose
F150W	1.5	0.375	11.2	General purpose
F200W	2	0.5	10.4	General purpose
F140M	1.4	0.14	28.1	Cool *s, H_2O steam
F162M	1.62	0.151	26.6	Cool *s, off-band
F182M	1.82	0.221	25.5	Cool *s, H_2O steam
F210M	2.1	0.21	25.7	CH_4
F164N	1.644	0.0164	268	[FeII]
F187N	1.8756	0.0188	267	Pα
F212N	2.1218	0.0212	265	H_2
F225N	2.2477	0.0225	232	H_2

Long Wavelength Module

Name	Center	Bandpass	Sensitivity	Use
F322W2	3.22	1.61		Background Min.
F277W	2.77	0.6925	12.3	General purpose
F356W	3.56	0.89	13.8	General purpose
F444W	4.44	1.11	24.5	General purpose
F250M	2.5	0.1667	38.1	CH_4
F300M	3	0.3	26.8	H_2O ice
F335M	3.35	0.335	28	PAH
F360M	3.6	0.36	29.7	BDs, planets
F410M	4.1	0.41	36.7	BDs, planets
F430M	4.3	0.2	71.5	CO_2
F460M	4.6	0.2	55.7	CO
F480M	4.8	0.4	72.6	BDs, planets
F323N	3.235	0.0324	240	H_2
F405N	4.0523	0.0405	260	Brα
F418N	4.1813	0.0418	271	H_2
F466N	4.656	0.0466	334	CO
F470N	4.705	0.0471	341	H_2

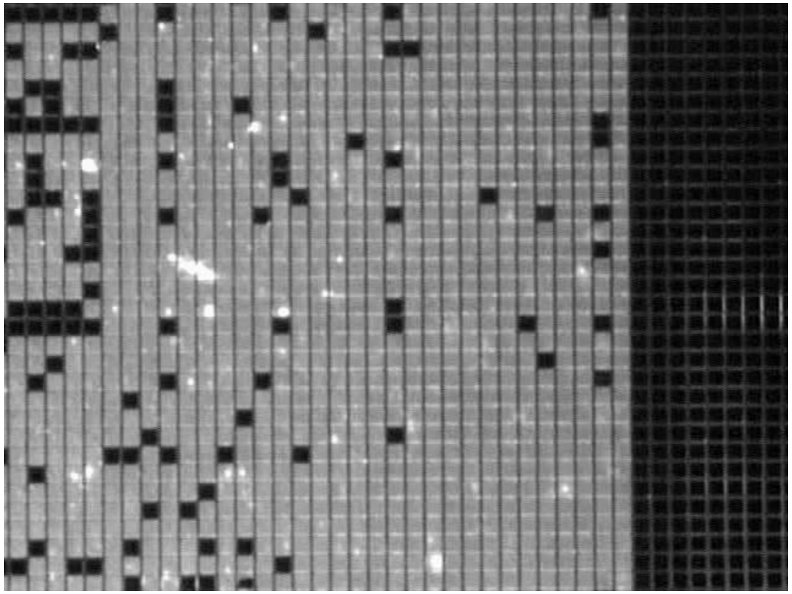
K ~ 15-16 mag star will get close to saturation in single 10.6-s frame with F200W

* Warning! Paradigm Shift: JWST filters shift the decimal point one place to the right

HST F300W = 0.3 um, JWST F300M = 3.0 um

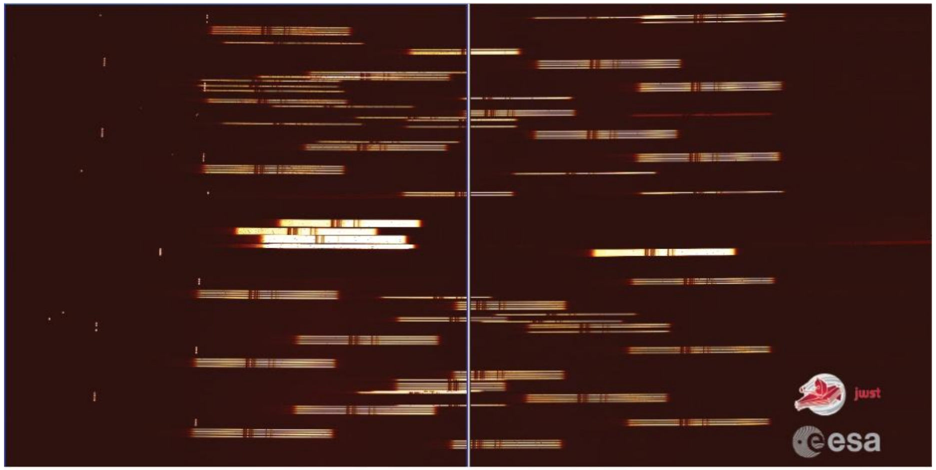
NIRSpec

- Micro-shutters
  - 730 x 342 array of 0.2" x 0.46" shutters (arranged in 4 quadrants)
  - 3.4 x 3.4 arcmin FOV
  - R=100, 1000, 2700
- Fixed slits
  - 3 available: 0.1" x 1.9", 0.2" x 3.3", 0.4" x 3.8"
  - R=100, 1000, 2700
- Integral Field Unit
  - 3" x 3" FOV
  - 30 slices, each 0.1" x 3"
  - R=100, 1000, 2700

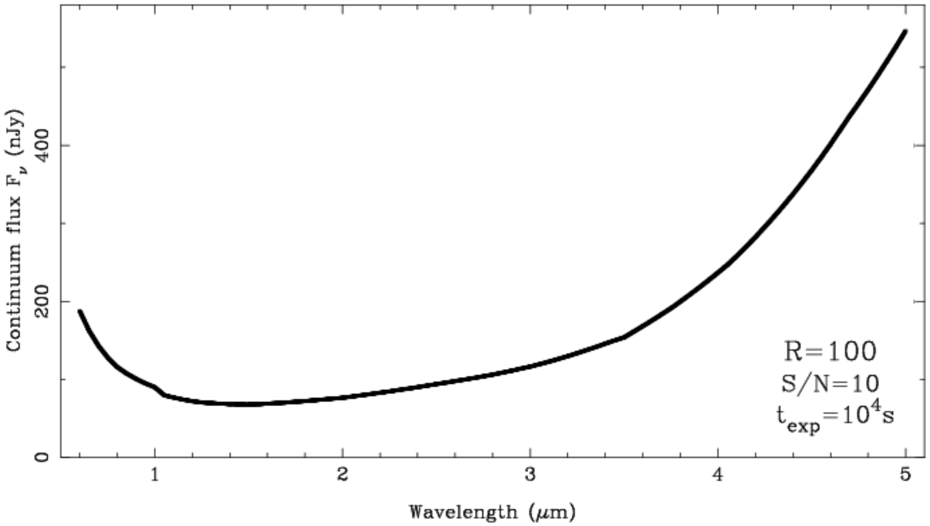


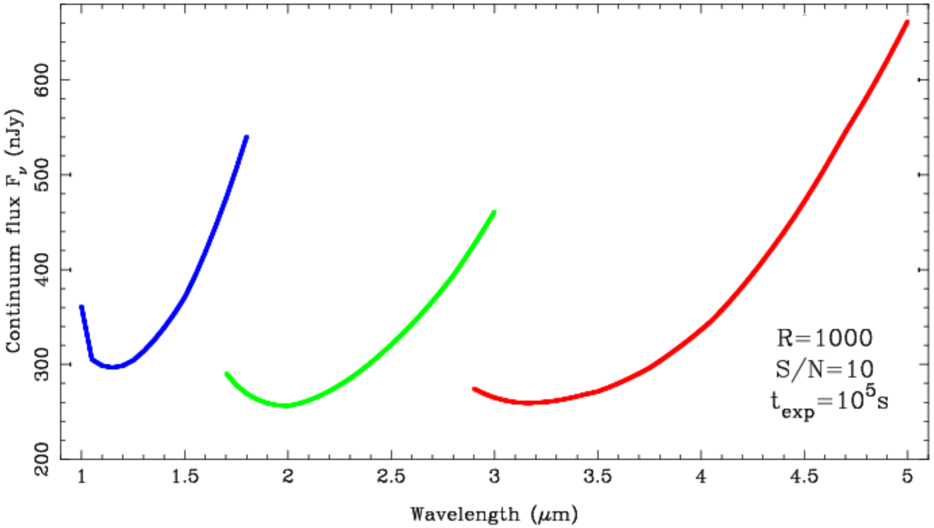
- R = 100: 0.7 - 5 μm with a prism
- R = 1000: 1.0 - 5.0 μm with 3 gratings
- R = 2700: 1.0 - 5.0 μm with 3 gratings

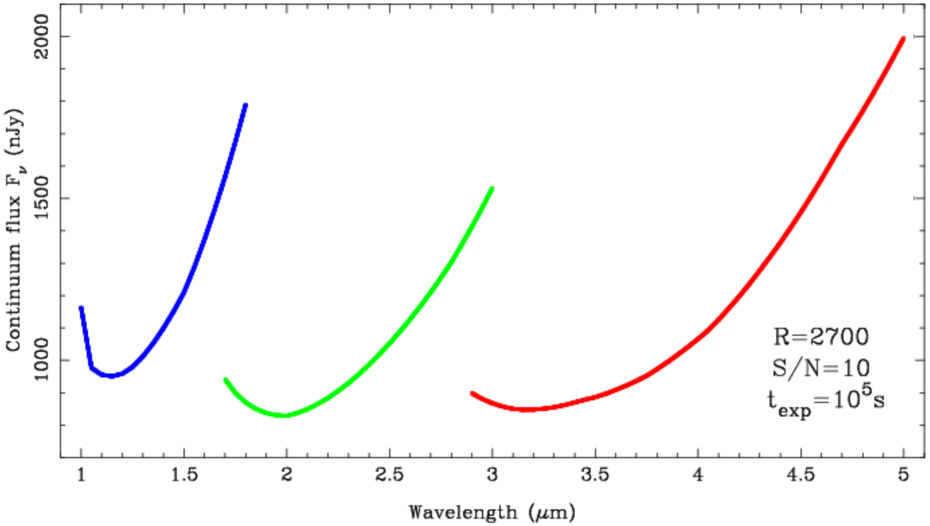
NIRSpec Sensitivity



JWST/NIRSpec - FM2 cyrogenic test campaign 01/2013





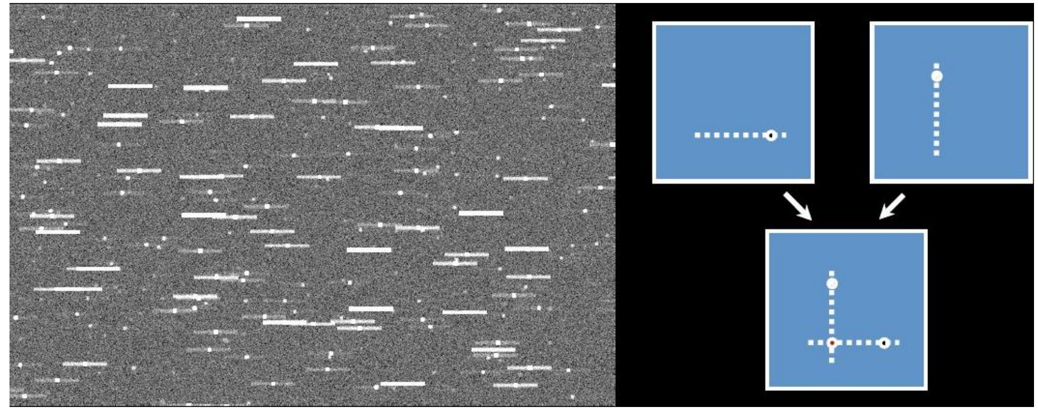


FGS/NIRISS

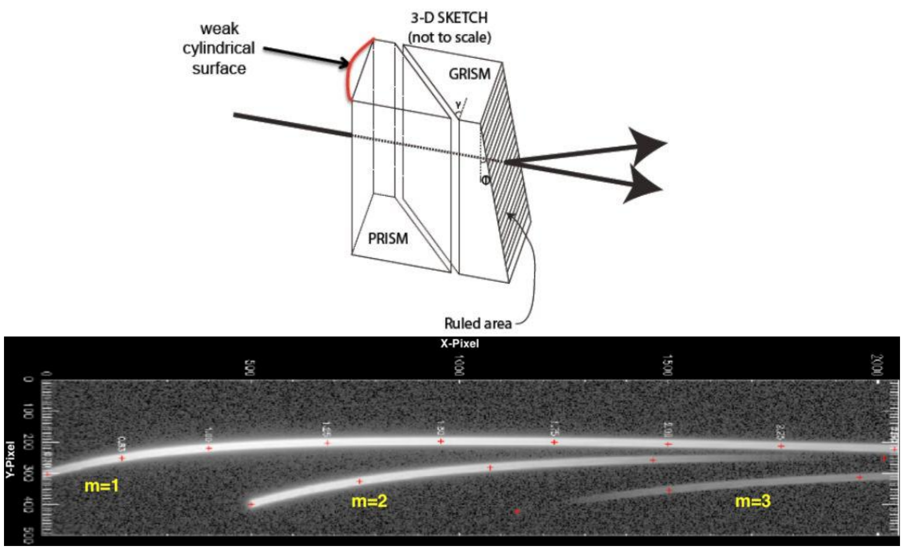
- FGS is dedicated to attitude control
  - 95% probability that a suitable guide star can be found, even at high galactic latitudes
- Near-Infrared Imager and Slitless Spectrograph
- 4 Modes:
  - Wide-field grism spectroscopy, 1 - 2.5 µm at R ~ 150
  - Single-object grism spect., 0.6 - 3.0 µm at R ~ 700
  - Aperture-masking interferometry, 3.8, 4.3, 4.8 µm
  - Broad-band imaging, 1.0 - 5.0 µm, 2.2’x2.2’

NIRISS Modes

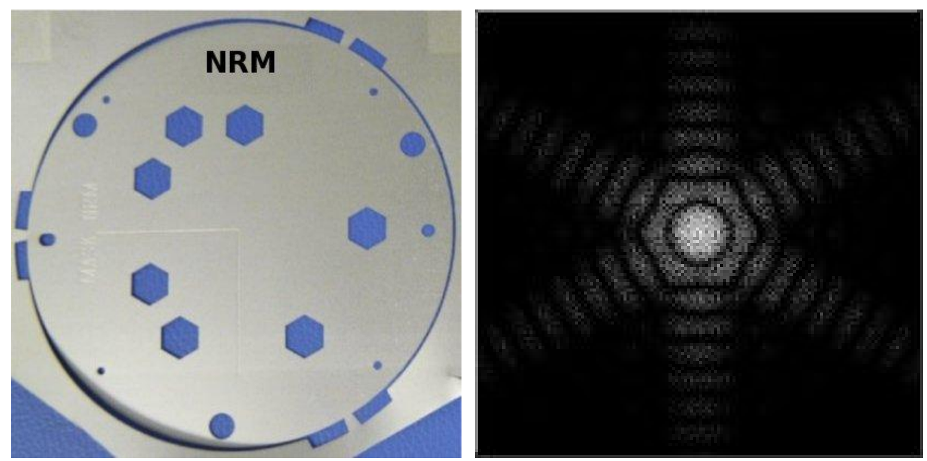
- WFSS uses two orthogonal grisms to deal with overlap
- SOSS blurs and twists spectra for better sampling and order separation
- AMI has baselines from 1.32 to 5.28 m for extremely well-controlled PSFs – resolve objects at 0.2” with Δm=9.5



WFSS spectra



SOSS Grism and spectrum



AMI mask and PSF

NIRISS Sensitivity

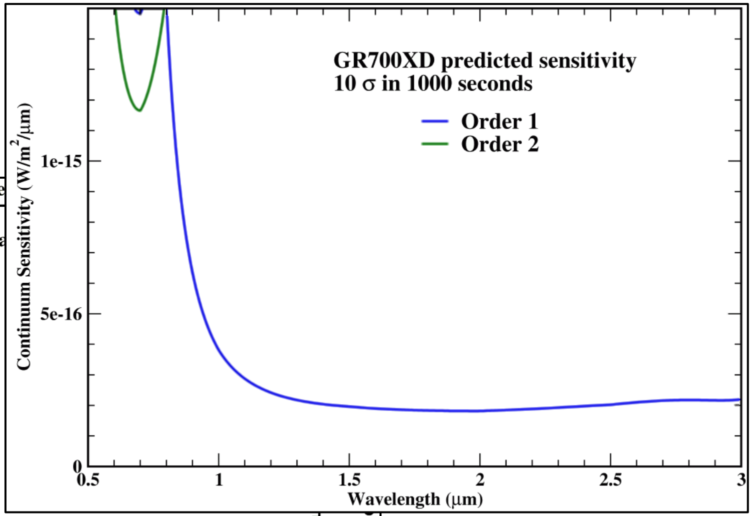
- Although imaging filters are similar to NIRCAM (a smaller selection, however) the sensitivity is a smidge better at short wavelengths and nearly a factor of 2 better at long wavelengths

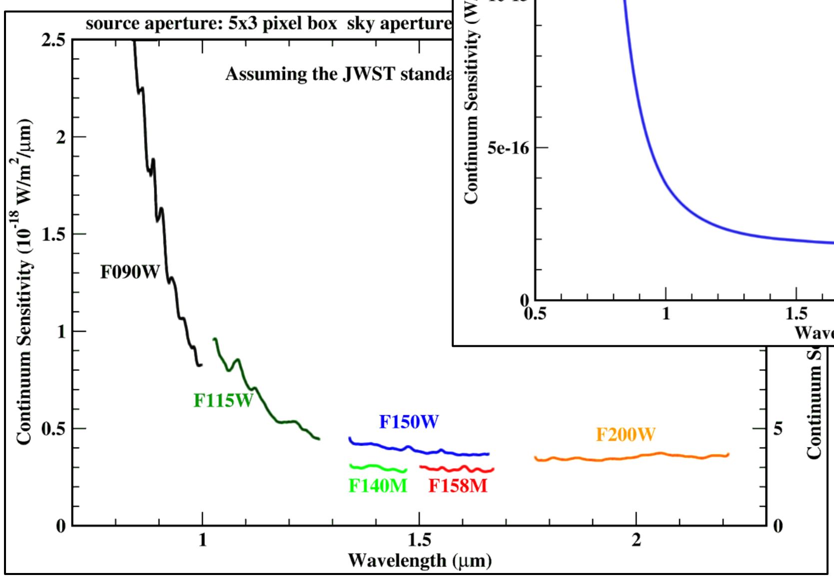
Imaging sensitivity

λ in µm, Sens. in nJy, 10σ in 10000 s

Name	Center	NIRISS Sensitivity	NIRCAM Sensitivity
F090W	0.90	11.3	14.3
F115W	1.15	11.2	11.8
F150W	1.50	9.2	11.2
F200W	2.00	7.8	10.4
F277W	2.77	6.6	12.3
F356W	3.56	6.9	13.8
F444W	4.44	12.3	24.5
F140M	1.40	14.8	28.1
F158M	1.58	12.9	---
F380M	3.80	18.7	---
F430M	4.30	28.32	71.5
F480M	4.80	36.85	72.6

SOSS sensitivity
(note 1000 s rather than 10000 s)



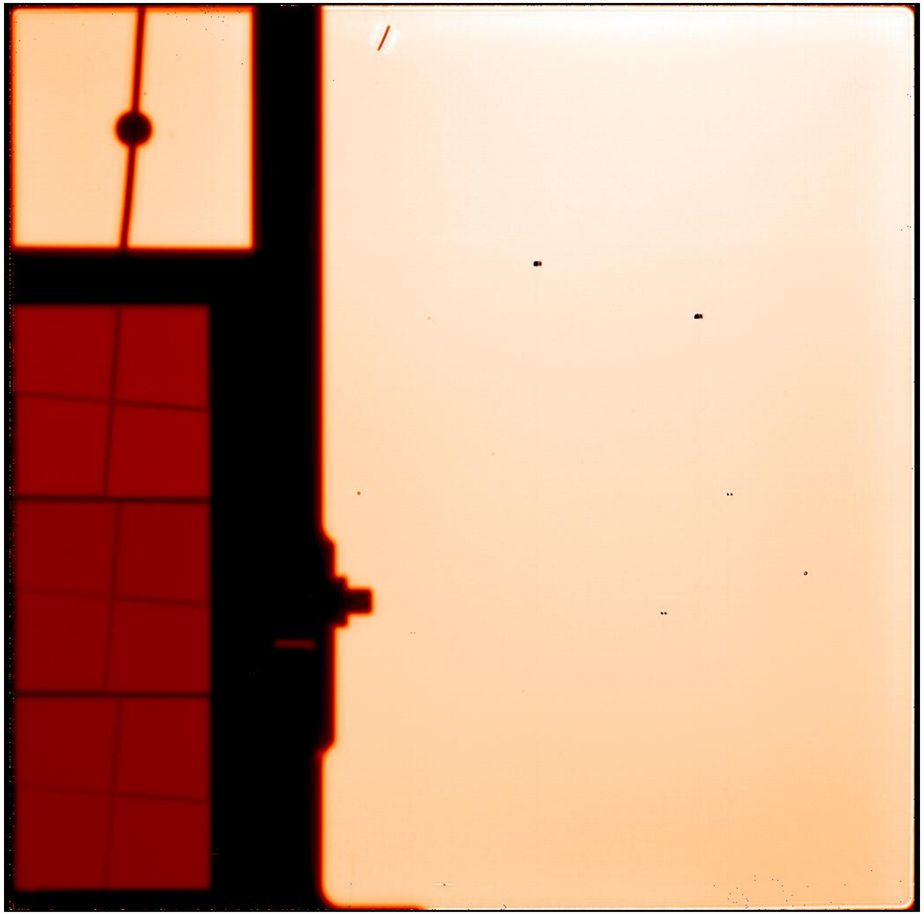


WFSS sensitivity

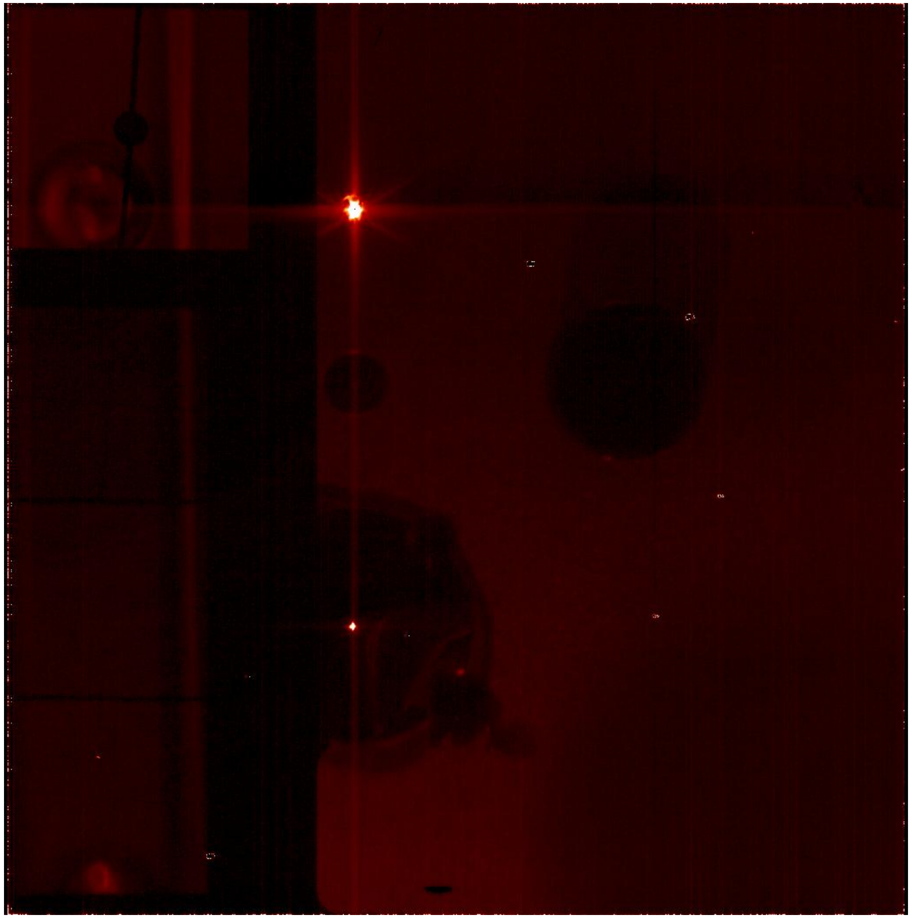
MIRI

- Imaging from 5.6 to 25.5 µm
  - 9 filters, 1.9 x 1.4 arcmin field-of-view
- Coronagraphy with suppressions ~ 500 - 1000
  - FQPMs at 10.65, 11.4, and 15.5 µm
  - Lyot for 23 µm
- Low res slit spectroscopy, 5 - 12 µm, R ~ 100
  - Can also be used slitless anywhere in the field
  - "Optimized" subarray for transit spectroscopy
- Medium res IFU spectroscopy with ~ 5" FOV, 5 - 28 µm, R ~ 3000

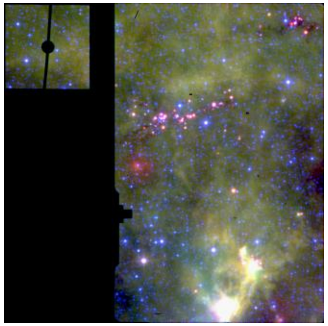
MIRI Imaging



Imager Flat Field Source

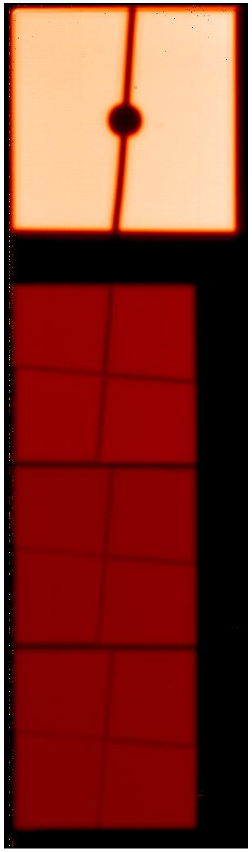


Imager Pinhole Sources



Example image field

MIRI Coronography



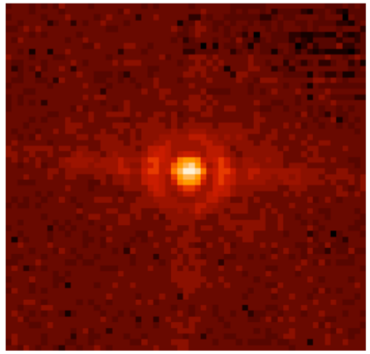


Figure 45: PSF at 11.4μm

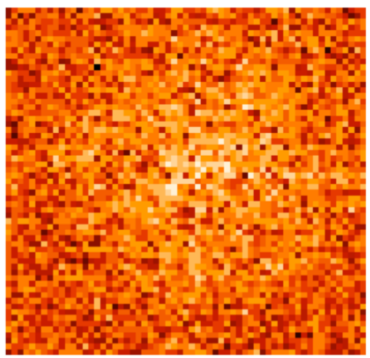


Figure 46: Coronagraphic image at 11.4μm

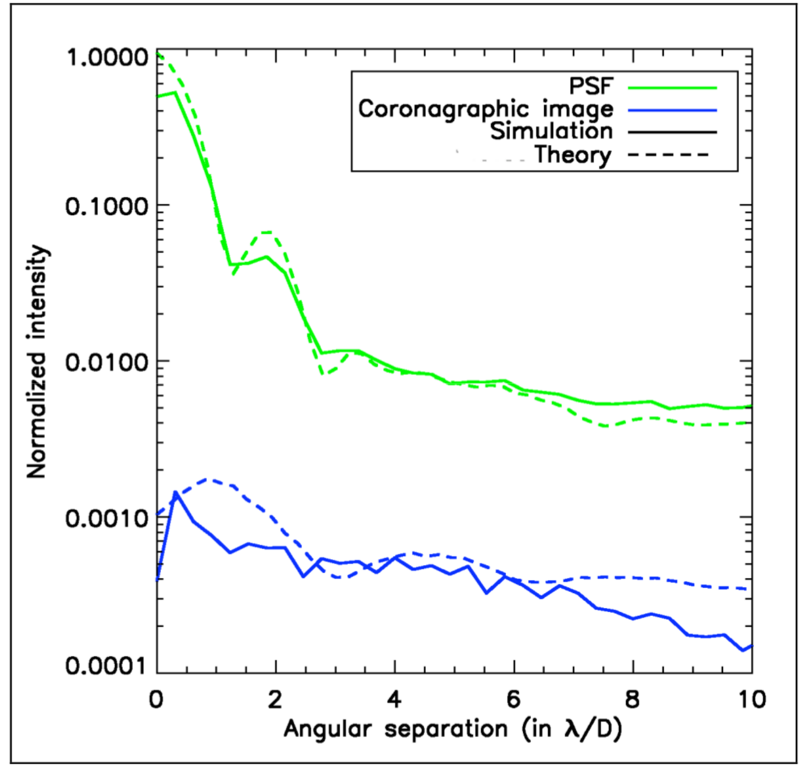


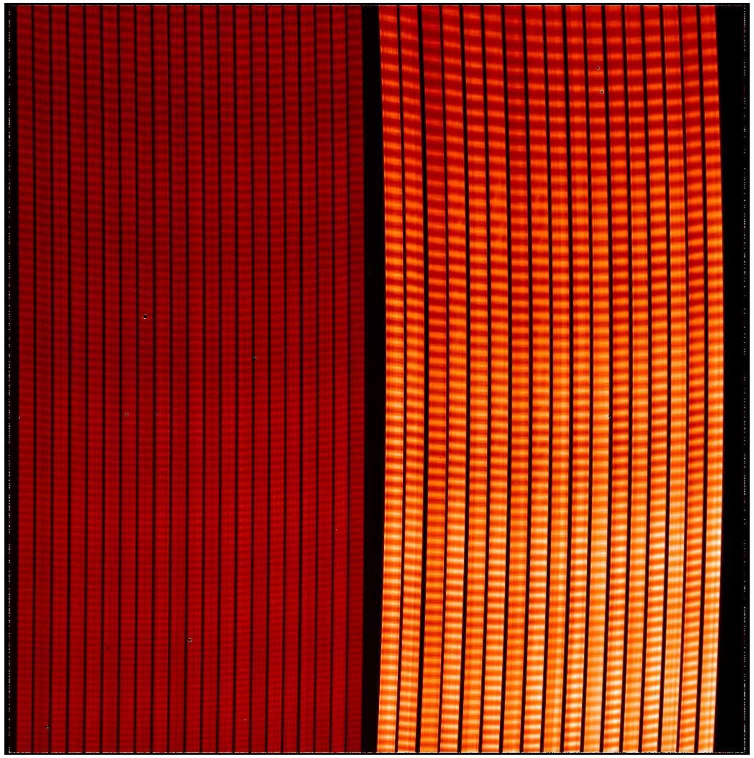
Figure 47: Normalized coronagraphic profile (blue line) and PSF (green line) compared to simulated profiles (doted lines) at 11.4μm

- Lyot coronagraph can be used with any filter, but 23 μm has an optimized mask
- You can put the source on the central disk, or on the supporting arms

MIRI Spectroscopy

Medium Resolution, Integral Field Unit Spectrometer

5.60 – 6.62 µm 8.71 – 10.34 µm



1B – Shortwave – 2B

20.69 – 24.68 µm 13.19 – 15.58 µm

4B – Longwave – 3B

- 3 grating positions needed to cover full wavelength range

Ch.\ Pos. (µm)	A	B	C
1	4.91 - 5.79	5.60 - 6.62	6.46 - 7.63
2	7.55 - 8.91	8.71 - 10.34	9.89 - 11.71
3	11.50 - 13.59	13.19 - 15.58	15.40 - 18.14
4	17.88 - 21.34	20.69 - 24.68	23.83 - 28.43

MIRI Filters & Sensitivity

Imaging Bands					
Name	Center	Bandpass	Sensitivity	Saturation	Use
F560W	5.6	1.2	0.2 μJy	7 mJy	General purpose
F770W	7.7	2.2	0.28 μJy	3 mJy	General purpose
F1000W	10.0	2.0	0.7 μJy	8 mJy	General purpose
F1130W	11.3	0.7	1.7 μJy	35 mJy	PAH
F1280W	12.8	2.4	1.4 μJy	15 mJy	General purpose, [NeII]
F1500W	15.0	3.0	1.8 μJy	18 mJy	General purpose
F1800W	18.0	3.0	4.3 μJy	34 mJy	General purpose
F2100W	21.0	5.0	8.6 μJy	50 mJy	General purpose
F2550W	25.5	4.0	28 μJy	105 mJy	General purpose

Coronagraph Bands			
Name	Center	Bandpass	Use
F1065C	10.65	0.53	NH_3
F1140C	11.40	0.57	Cont., DD PAH
F1550C	15.50	0.78	BB Continuum
F2300C	23.00	4.60	Debris disks

Spectroscopic Modes				
Name	Center	Resolution	Sensitivity	Saturation
LRS	7.5	100	3 μJy	70 mJy
MRS 1	6.4	3500	0.7×10^{-20} W m^{-2}	2.5 Jy
MRS 2	9.2	2800	1.0×10^{-20} W m^{-2}	1.5 Jy
MRS 3	14.5	2700	1.2×10^{-20} W m^{-2}	2.5 Jy
MRS 4*	22.5	2200	6.0×10^{-20} W m^{-2}	3 Jy

* Caveat: The MRS Channel 4 grating has a manufacturing defect that reduces the throughput to only 25% of its design value. This x2 reduction in sensitivity is not yet taken into account here.

Operations

Operations Planning

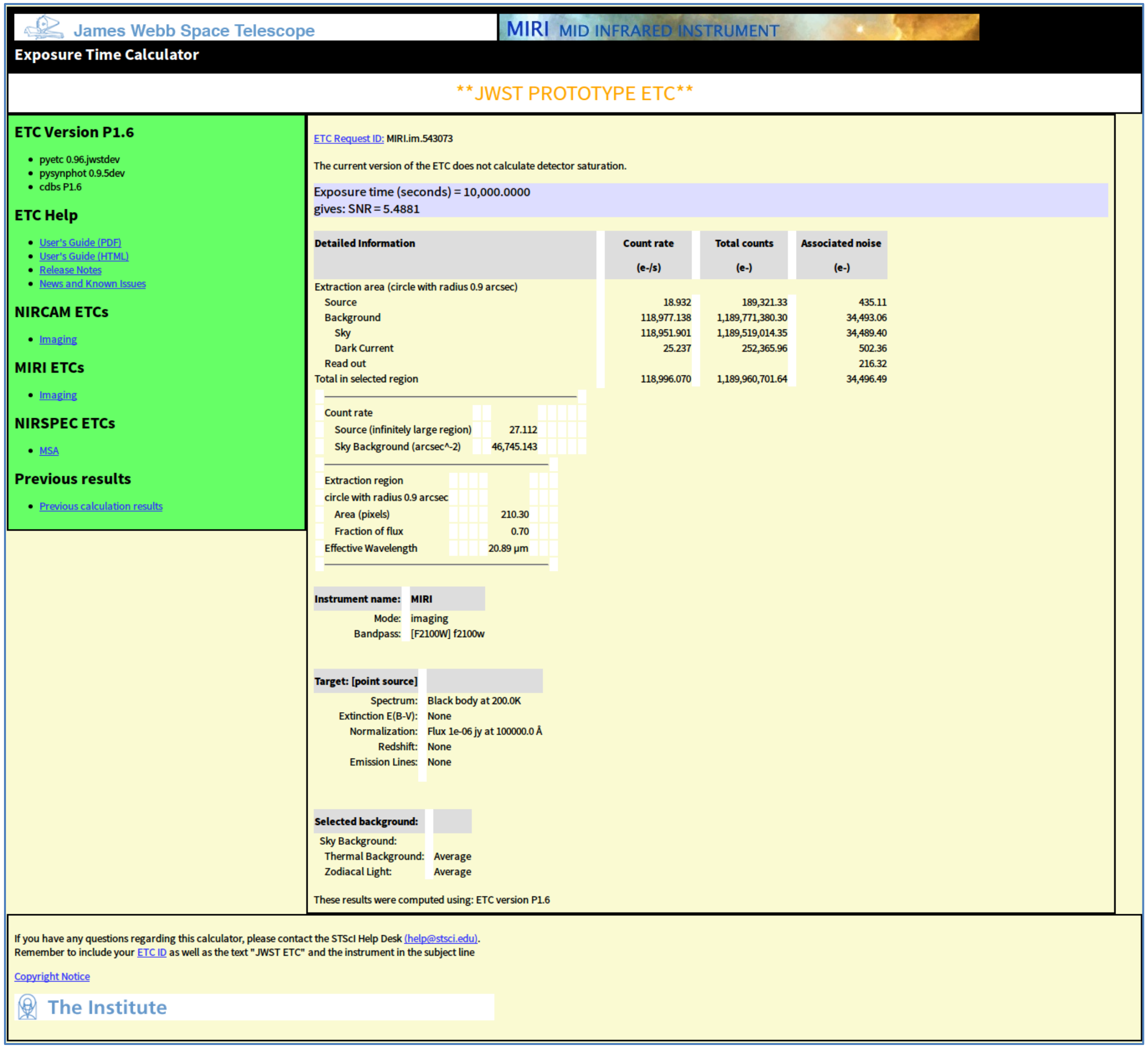
- Draft planning tools are available from STScI
- Very drafty and incomplete
  - Only a few basic modes are implemented
  - Many placeholders (e.g. instrument fields-of-view)
  - Need updates to as-built performance
- Comments and bug reports are being actively solicited
- Good enough to begin serious daydreaming

Exposure Time Calculator (ETC) – 1

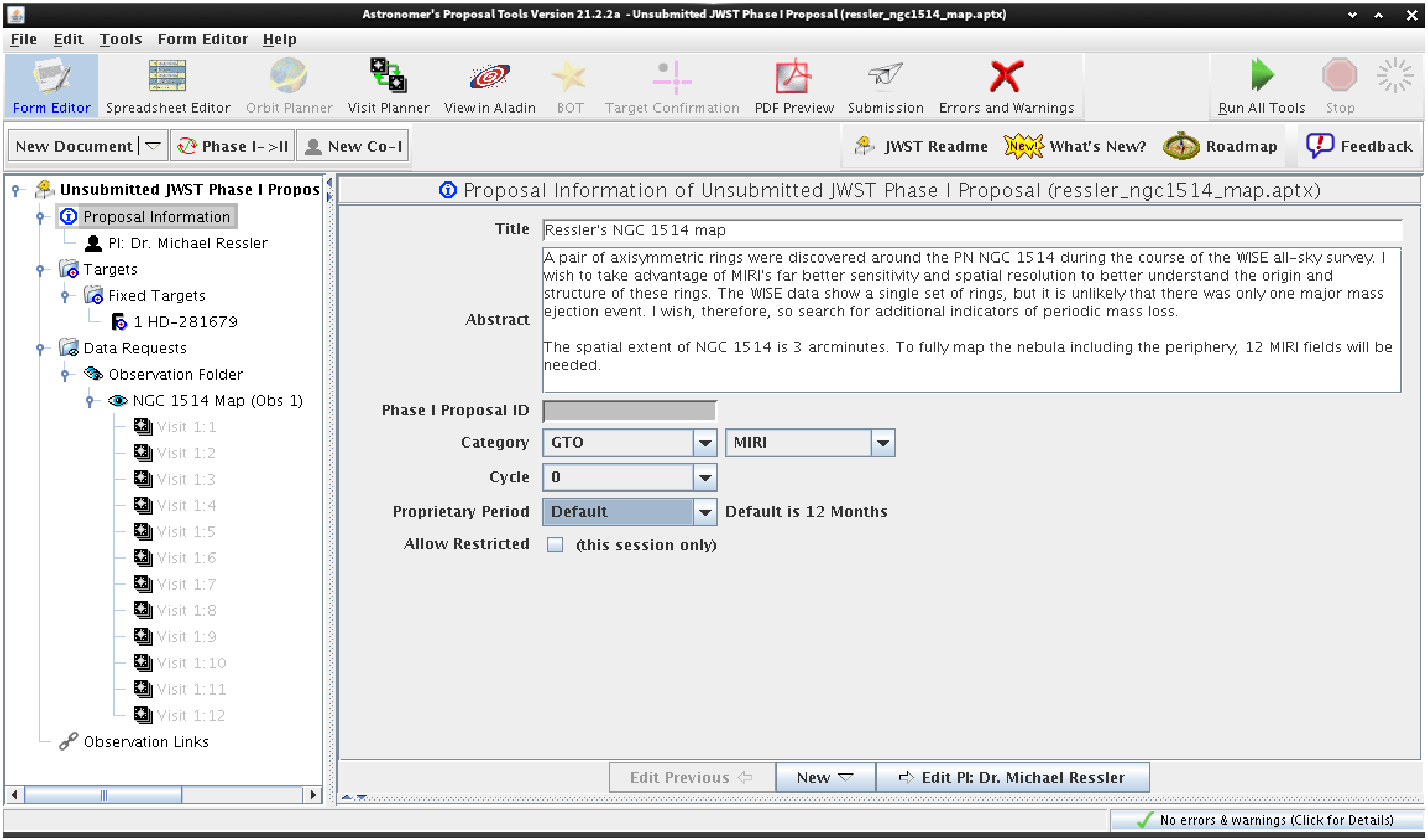
- jwstetc.stsci.edu
- Very incomplete: no saturation, etc.
- Imaging mode + NIRCAM MSA only
- However, it will give a very nice intro to the capabilities and force you to rethink some things!

Exposure Time Calculator (ETC) – 2

- jwstetc.stsci.edu
- Very incomplete: no saturation, etc.
- Imaging mode + NIRCAM MSA only
- However, it will give a very nice intro to the capabilities and force you to rethink some things!

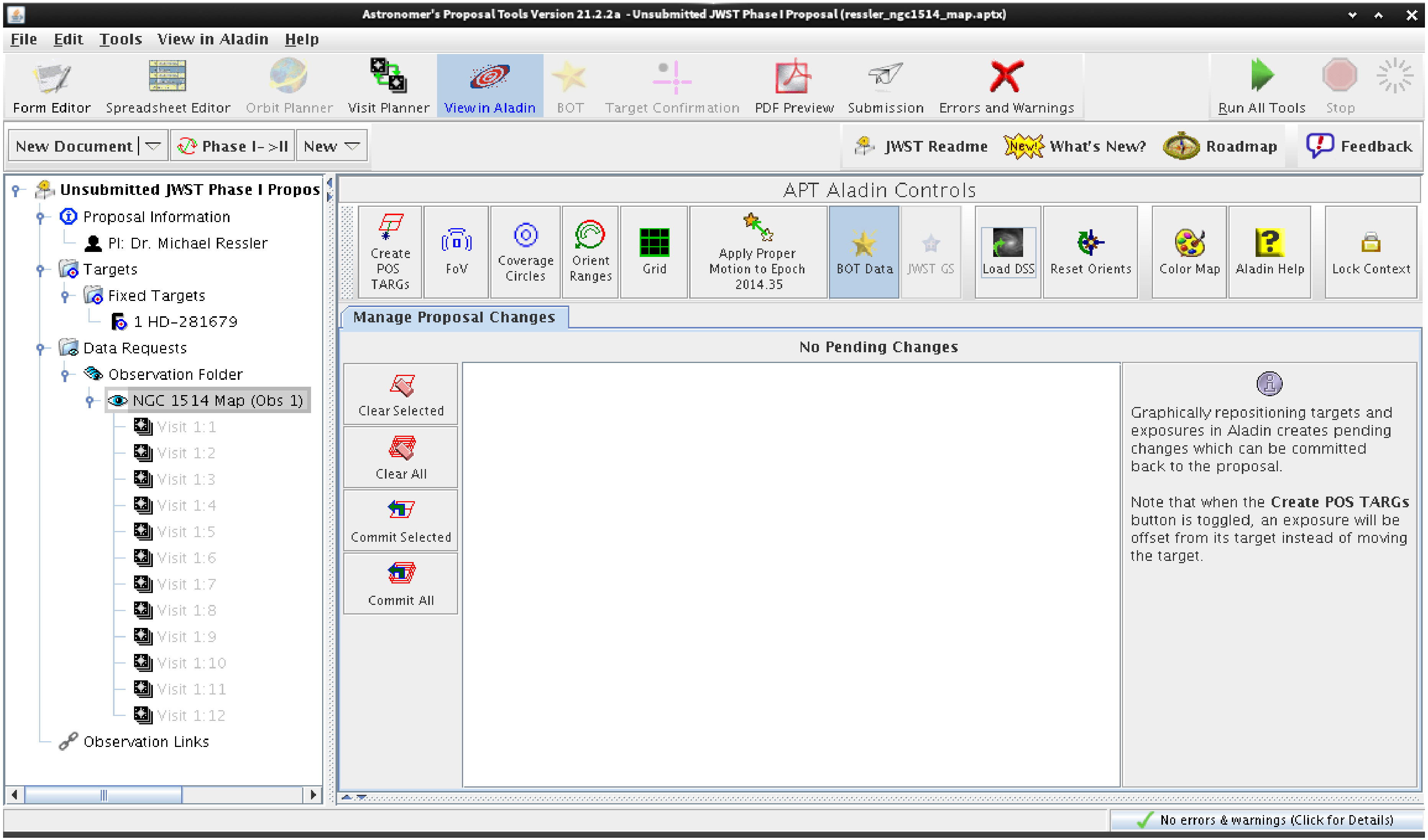


Astronomer's Planning Tool (APT) – 1



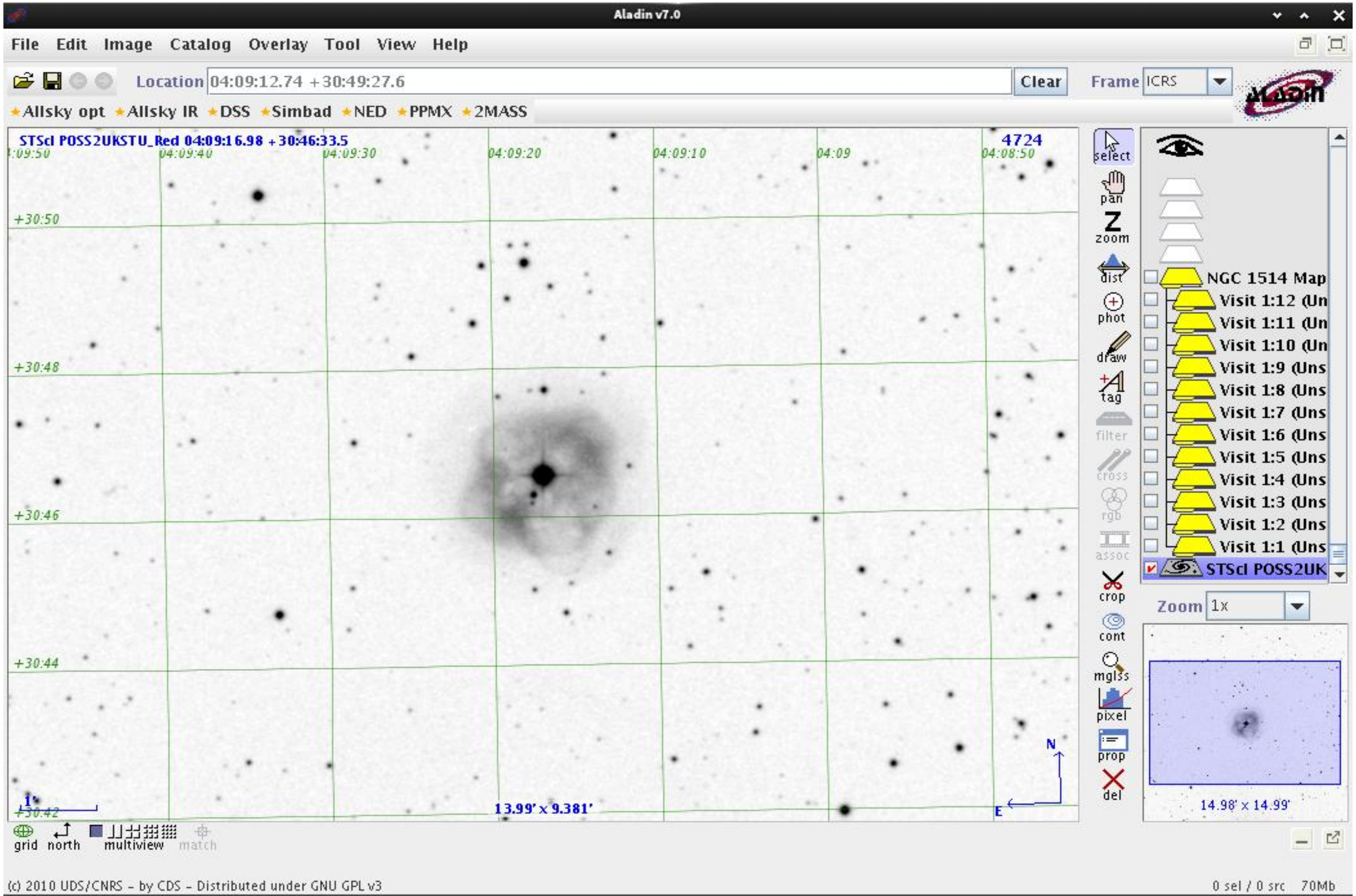
- www.stsci.edu/hst/proposing/apt

Astronomer's Planning Tool (APT) – 2



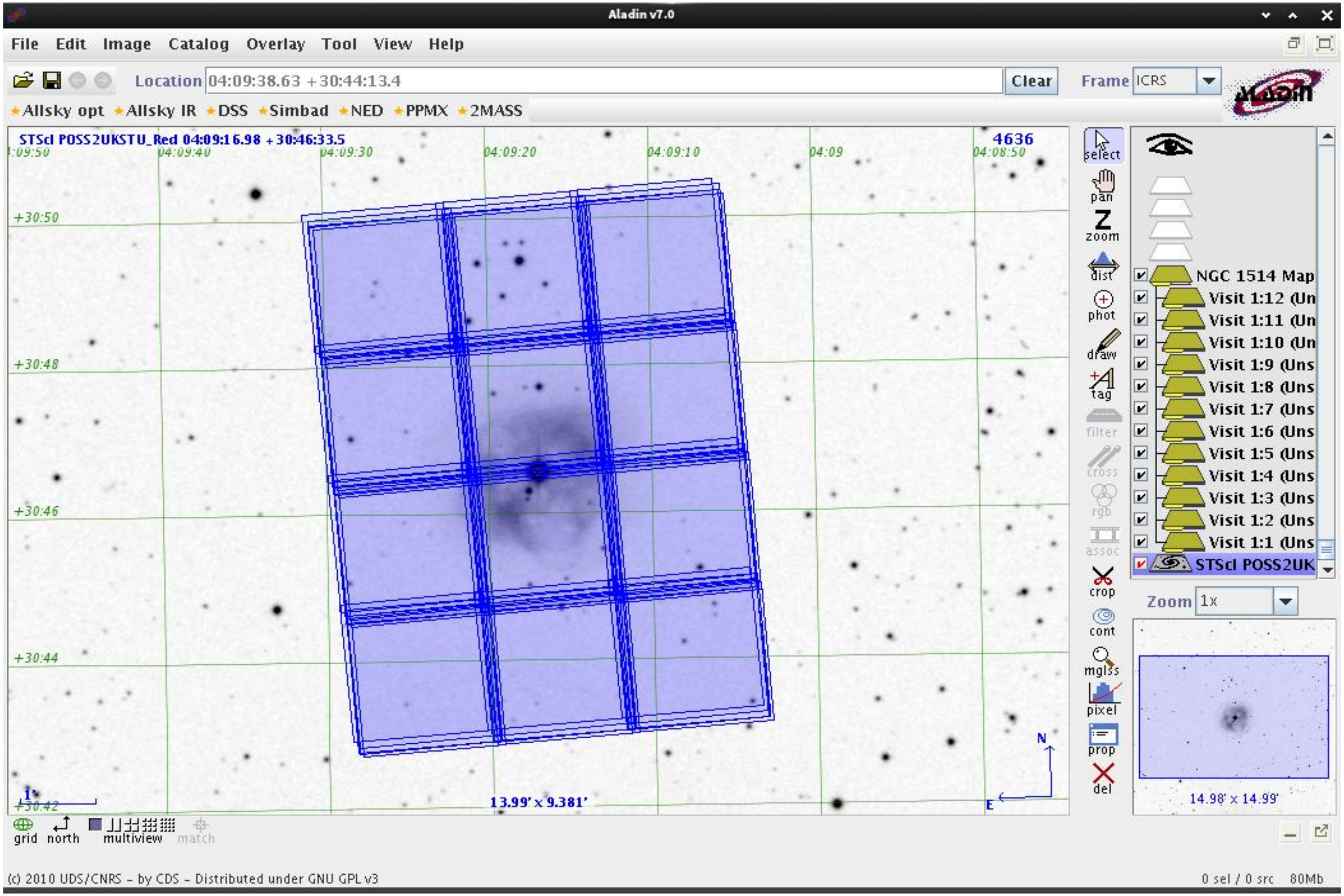
- www.stsci.edu/hst/proposing/apt

Astronomer's Planning Tool (APT) – 3



- www.stsci.edu/hst/proposing/apt

Astronomer's Planning Tool (APT) – 4



- www.stsci.edu/hst/proposing/apt

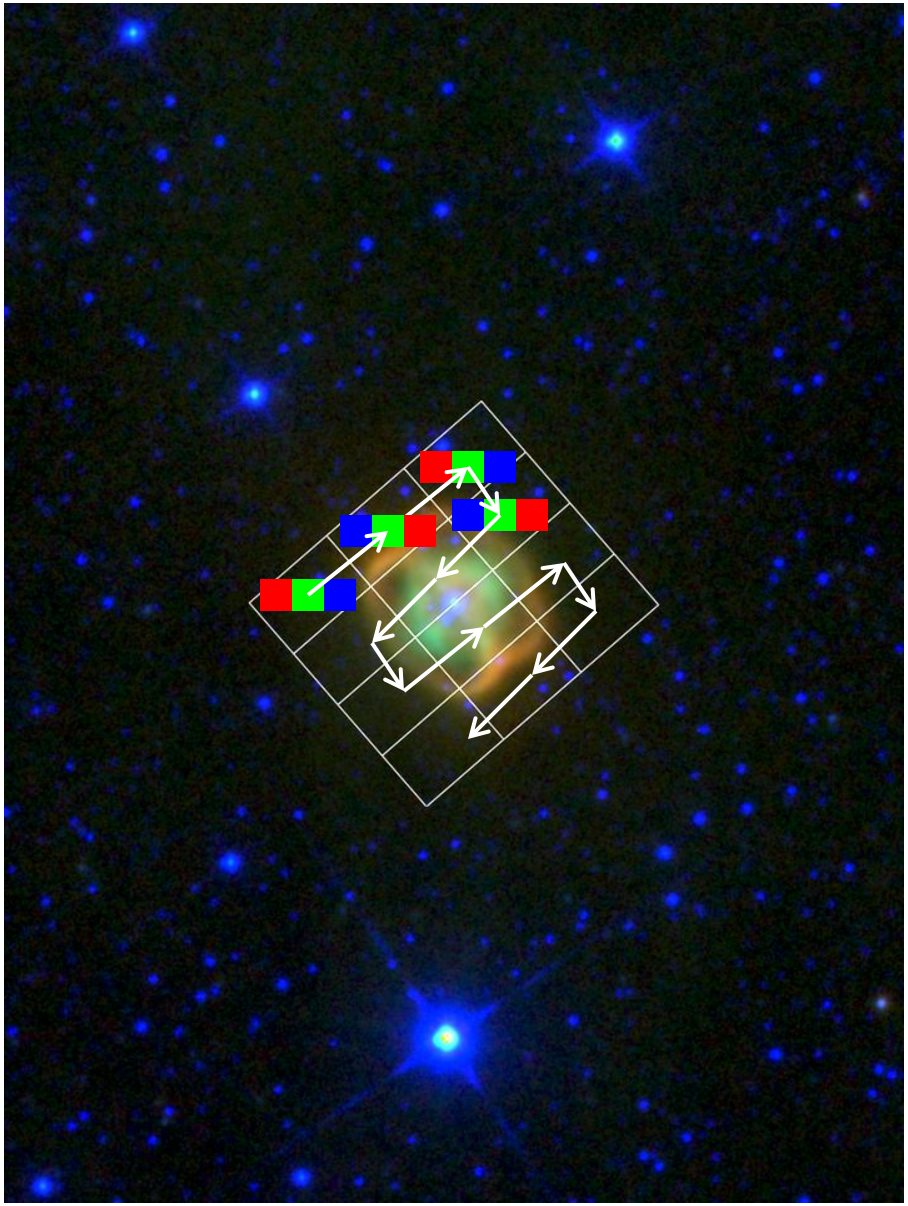
Operational Constraints

- It's slow
  - 90 deg/hr slew rate
- Target acquisition and guide star acquisition can be tedious – wait for propellant slosh to stop
- Instrument setup and mechanism movements are laborious due to thermal disturbance issues
- Many timing and scheduling constraints
- Then you get to worry about exposure time

Taxes (Current Thinking)

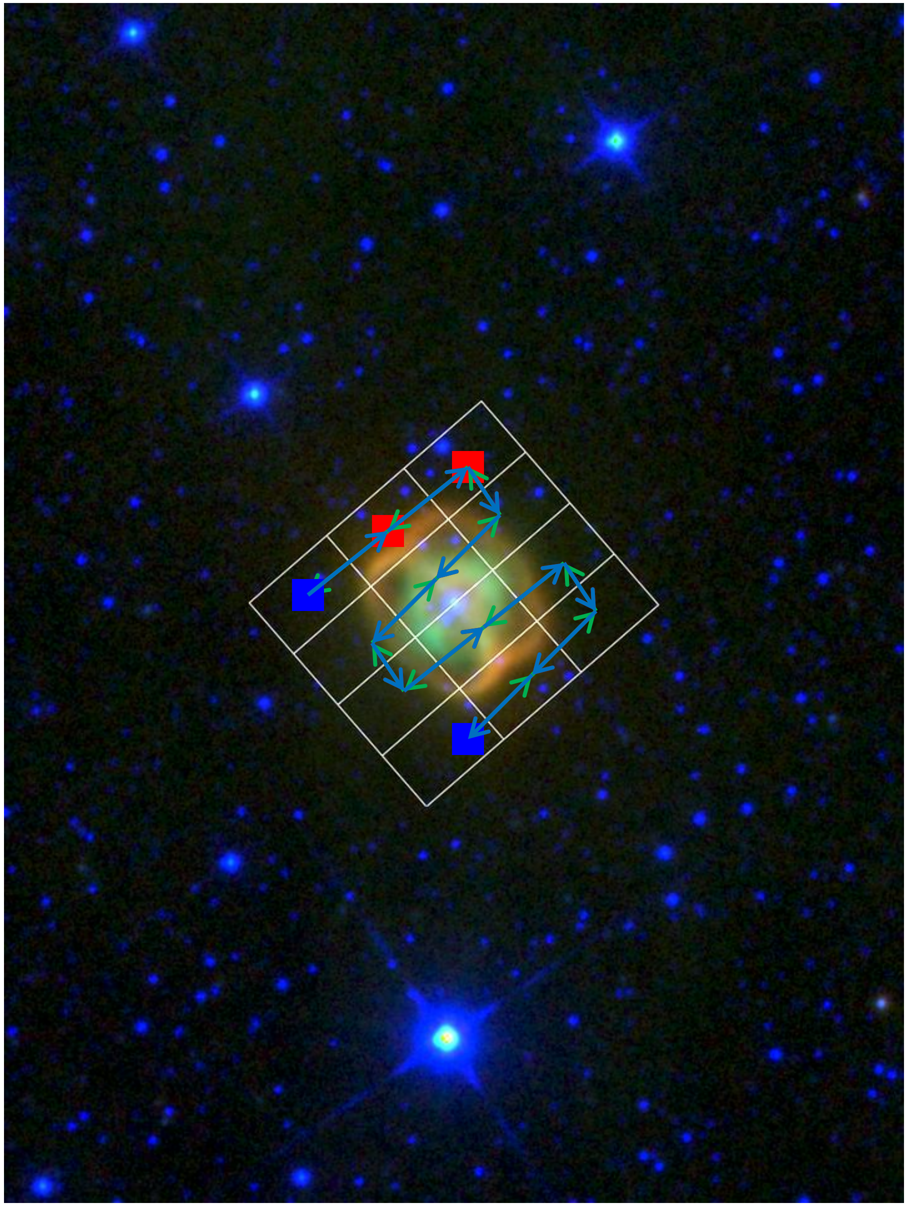
- Slew – 30 min
- Guide star acq – 4 min
- Dither moves – 0.5 min
- Filter moves – 2 min
- Indirect overheads (cal + observatory) – 16%
- This is NOT Spitzer (or HST)!!!
  - Designed for detailed study of a few objects, not broad surveys of complete samples
  - Will require different methods of attacking problems

Example: Mapping?



- Need 12 fields (3x4) to get decent coverage
- Overheads:
  - ½ hr to get there
  - N x 4 min guide star acq.
  - N-1 x 4 x 0.5 min dither offsets
  - M filters – do ABC in one field, CBA in next, N x (M-1) x 2 min
  - So, assuming 12 fields, 5 dithers, and 3 filters: 30 + 12 x 4 + 11 x 2 + 12 x 4 x 0.5 + 24 x 2 min
  - 2.9 hours not counting actual integration time
  - 24 filter moves – NOT ALLOWED!

Example: Mapping?

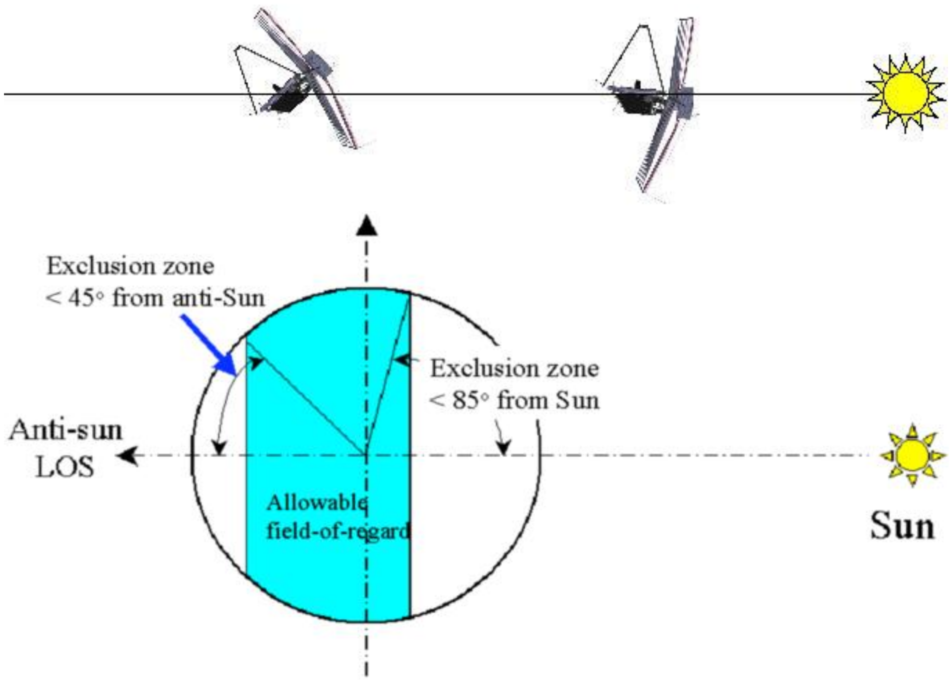


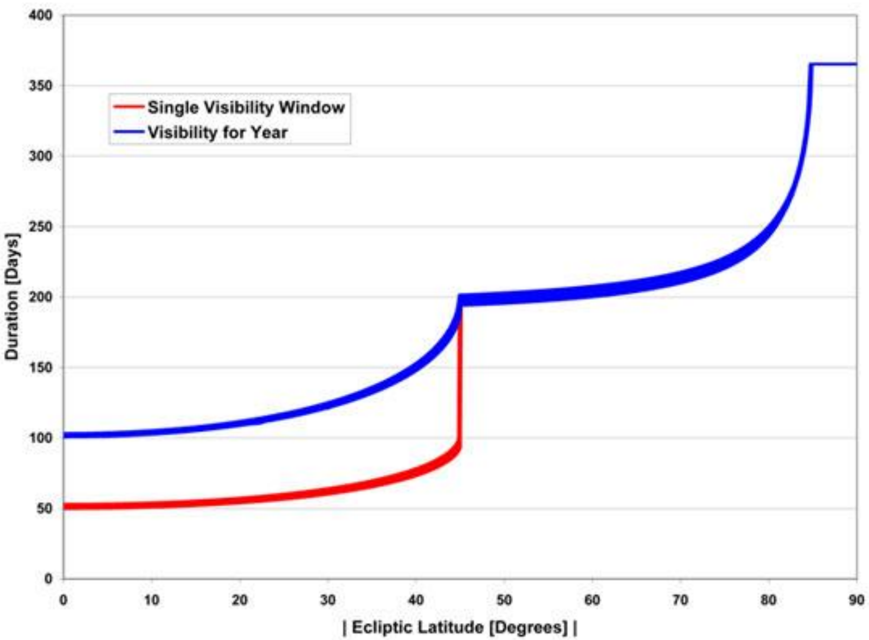
- Need 12 fields (3x4) to get decent coverage
- Overheads:
  - ½ hr to get there
  - M x (N x 4 min)-(2 x 4 min) guide star acq.
  - M x (N-1 x 4 x 0.5 min) offsets
  - M filters – (M-1) x 2 min
  - So, assuming 12 fields, 5 dithers, and 3 filters: 30 + 3 x 12 x 4 – 8 + 3 x 11 x 2 + 3 x 12 x 4 x 0.5 + 2 x 2
  - 5.1 hours (!) not counting actual integration time
  - But only 2 filter moves

Orientation Issues

- Strict pointing limitations due to limited field-of-regard (next slide)
- Allowed to chose available instrument aperture PA, but not spacecraft orientation
- Instrument position angle is considered a scheduling constraint

Field of Regard





Viewing zones dictated by need to keep the telescope well behind the sunshade

Number of days available depends strongly on ecliptic latitude:

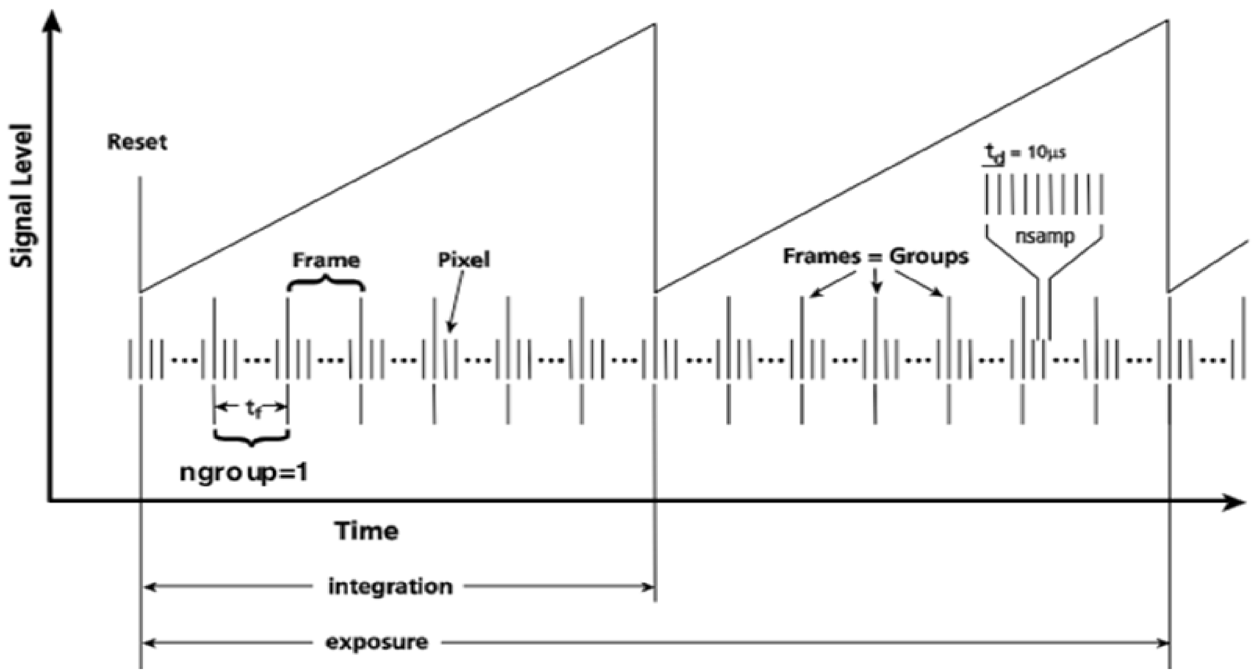
- Above 85°, always visible
- Between 45° and 85°, broadly visible for a continuous period
- Less than 45°, visible in two periods per year

Data Processing

Data Processing & Pipeline

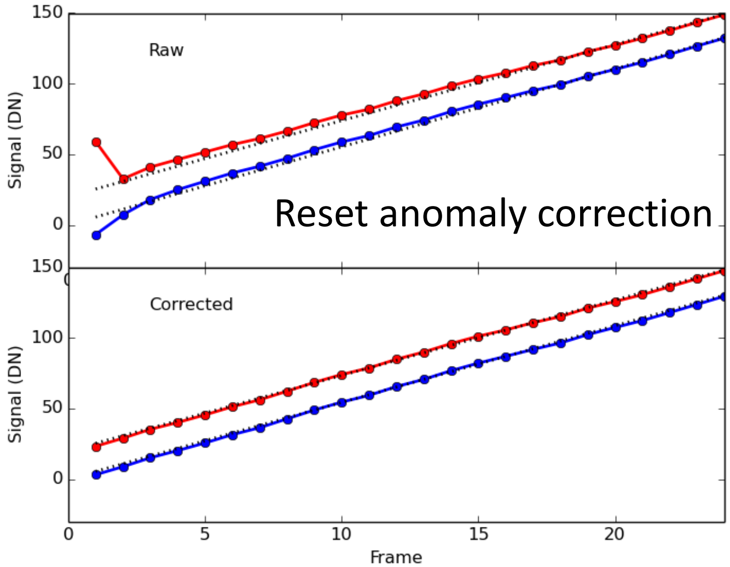
- All data on JWST is some form of "MultiACCUM"
  - Glorified sample-up-the-ramp with various types of averaging; MIRI will usually send down all data
  - This means humungous data sets
    - Typical 15 min Fastmode exposure with MIRI is 814 MB

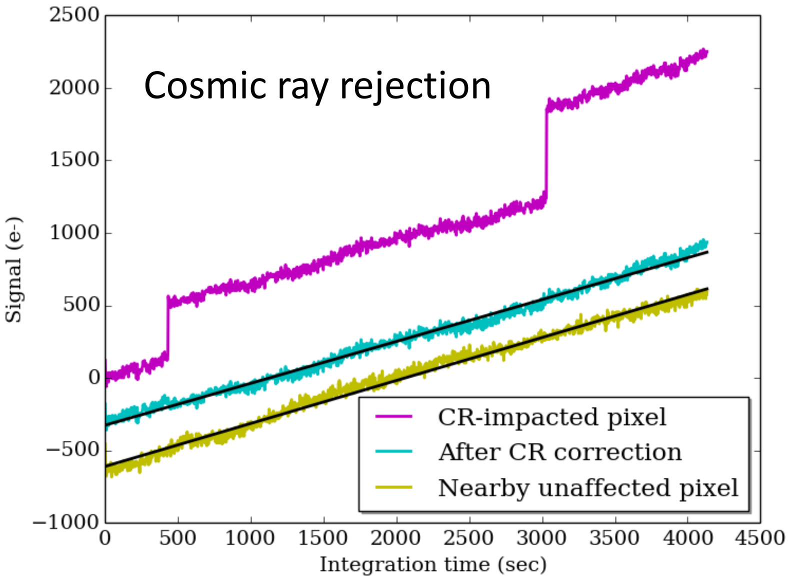
Example MIRI "Slowmode" exposure with 10 samples of every pixel (averaged on-board), 1290x1024 pixels per frame, 7 frames per integration, 2 integrations per exposure = 35 MB



Ramps-To-Slopes

- Level 2 data ("ramps-to-slopes") will be generated for all data
  - Will take care of all the usual and not-so-usual effects when converting raw data to electron rates
  - Non-linearity, reset anomaly, cosmic ray strikes, pull-up/pull-down, darks, references, e-/DN, etc.



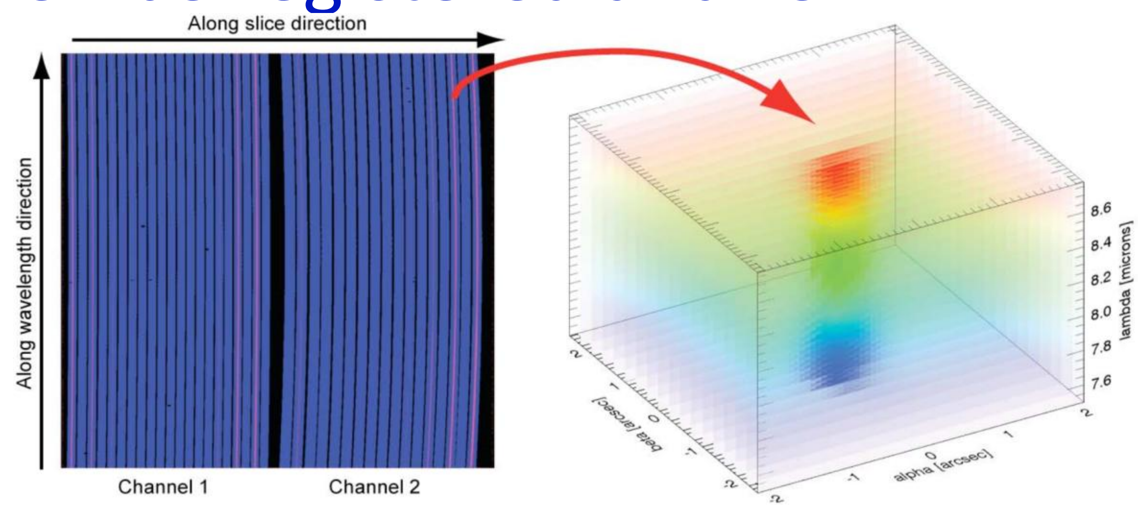


Data Processing - Imaging

- Next step depends on instrument/mode
- Images will go through background subtraction, flat-fielding, latent suppression, distortion correction, conversion to astrophysical fluxes
- Then off to positional referencing, coadding, mosaicing, etc.
- Roughly similar process for coronagraphy

Data Processing - Spectroscopy

- Spectroscopy will also go through background subtraction, flat-fielding, and latent suppression
- Spatial distortion correction, wavelength calibration, and fringe correction will follow, then conversion to astrophysical fluxes
- IFU data will be then be registered and re-assembled into a data cube (x, y, λ)



What Data Level Do I Want?

- Unless you are excrutiatingly pedantic about your data and think there is a conspiracy against your program, you will *almost* never want to play with raw/Level 1 data (even for high stability transit stuff)
- You might want to play with Level 2 if you are trying to dig every last gold flake out of the dirt
- Usually Level 3+ is okay, since it will represent our best current understanding of the data (doesn’t mean it can’t be reprocessed later)

Data Policy

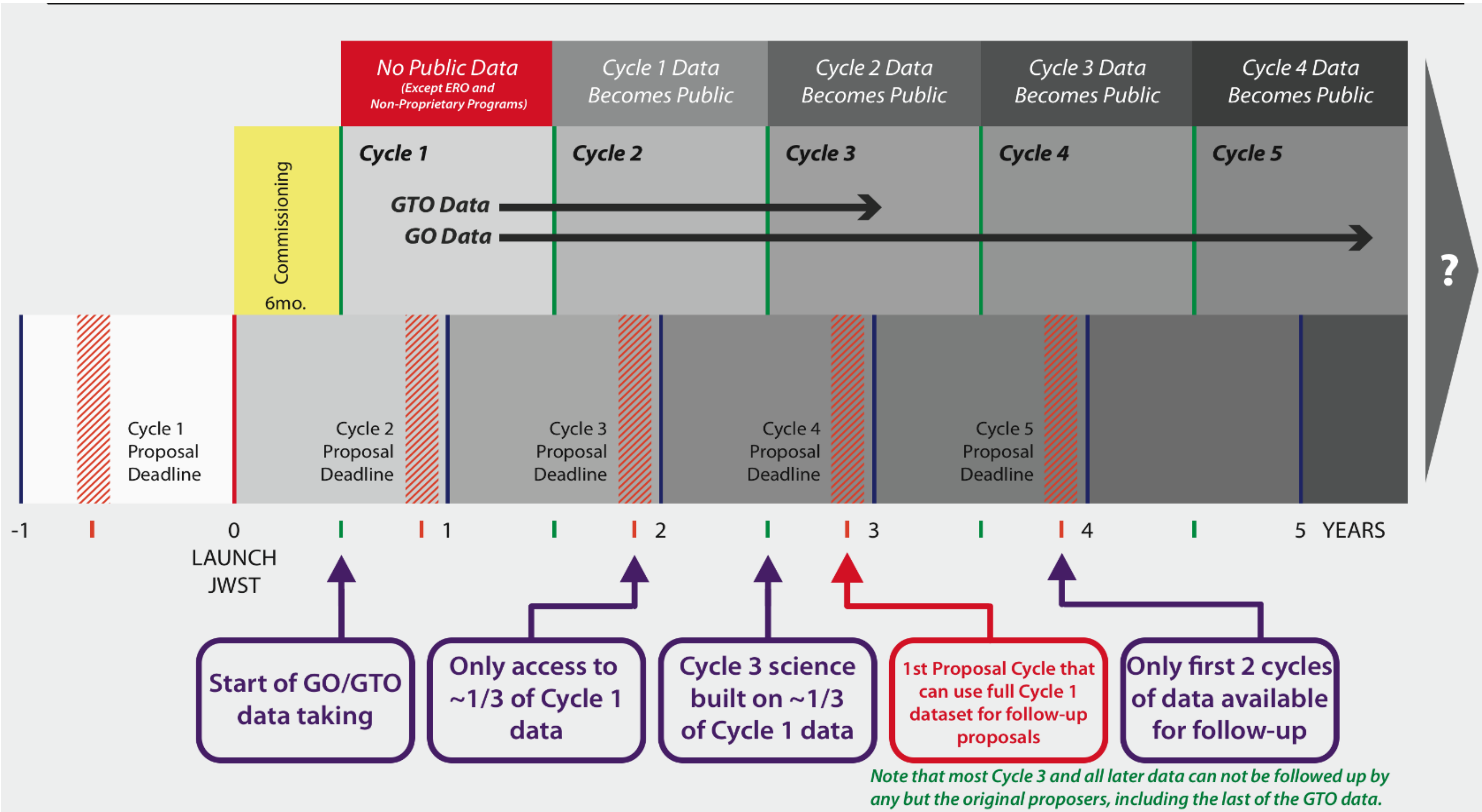
Classes of Observing Programs

- Guaranteed Time Observations – granted to instrument teams, some SWG members, or other AO selection agreements – 12 mo proprietary time
- Early Release/First Look (proposed) – similar to Spitzer, get data demonstrating key modes of the instruments into community hands as quickly as possible – 0 proprietary time
- Treasury/Legacy (proposed) – similar to HST and Spitzer, large competitively-selected projects – 0 proprietary time unless short time proposed
- Community Fields (proposed) – fields where the Great Observatories have already invested heavily, e.g. CDF-s, HDF-n, etc. - 0 proprietary time
- Guest Observer – competitively selected as normal – don't count on having proprietary time

Proprietary Time Issue

- JSTAC (JWST Advisory Committee) chartered to "advise the STScI director on the optimum strategies and priorities ... to maximize its [JWST's] scientific productivity."
  - JWST is a limited-life, 5 yr mission (10+ yr goal)
- Realization that only 1/3 of Cycle 1 data will be available to inform Cycle 3 proposals – this is stuff people will presumably want to follow up
- General society push to make access to taxpayer funded data more open
- Both together push proprietary time ("exclusive use time") toward zero

Proposal Cycle vs Proprietary Time



Proprietary Time Alternatives

- What about a 6 mo proposal cycle?
  - Does anyone really want to have TAC meetings twice per year? Expensive and exhausting with only minor improvement in data availability
- What about a 6 mo proprietary time?
  - All Cycle 1 data is available before Cycle 3 deadline
  - All Cycle N proposals can use all of Cycle N-2 data
- This is the current JSTAC ("JWST Space Telescope Advisory Committee") recommendation (12 mo cycles, 6 mo proprietary)

Pressure on GTOs

- “Based on Eric’s email, you*, the GTOs, can do what you like regarding fields, but we would like to ask you to think about the impact of your decisions and their impact on ‘maximizing the science return’.”
- “The JSTAC recognizes the GTO rights that have been granted by NASA, ESA and CSA, but would like to ask you to voluntarily agree to releasing data after 6 months. — We humbly ask for your munificence.”

* I get 60 hours of GTO time, and by launch, I will have been working on MIRI or its concept for over 21 years … you can guess my feelings about this request.

Wrap-up

What’s Next?

- [Possible repeat of this talk for those who missed it but are interested]
- ½ day workshop?
  - More details about each instrument’s capabilities
    - Especially caveats
  - Worked examples of some realistic projects
  - Guest science talk(s)
  - *I’d like your input!*
- Ultimate goal – help JPL teams get a head start in assembling winning proposals

Resources (Not even close to exhaustive!)

- Observatory/Instrument general information:
  - http://jwst.gsfc.nasa.gov
  - http://www.stsci.edu/jwst
- Science cases:
  - http://www.stsci.edu/jwst/doc-archive/white-papers
  - http://www.stsci.edu/institute/conference/jwst2011/talks
    - webcasts available if you look hard enough
  - http://www.stsci.edu/jwst/science/sodrm
- Operations/Policies:
  - http://jwstinput.wikidot.com/jwstoperations
  - http://www.stsci.edu/jwst/advisory-committee
- Tools:
  - http://jwstetc.stsci.edu/etc
  - http://www.stsci.edu/hst/proposing/apt